Aug. 11, 1953 H. SOHON ET AL 2,648,811

PHASE SHIFTER

Filed July 20, 1948

Fig. 1.

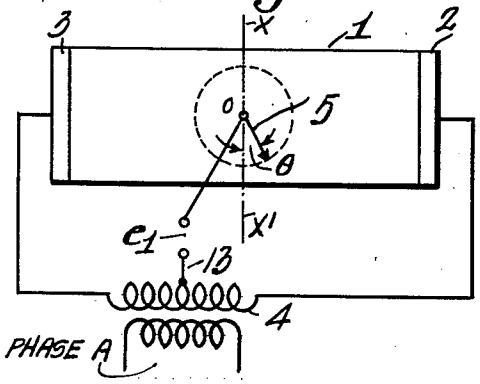


Fig. 2.

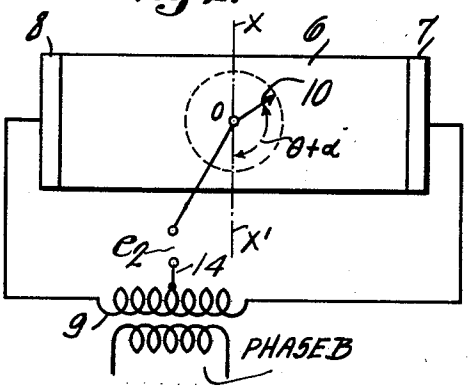


Fig. 3.

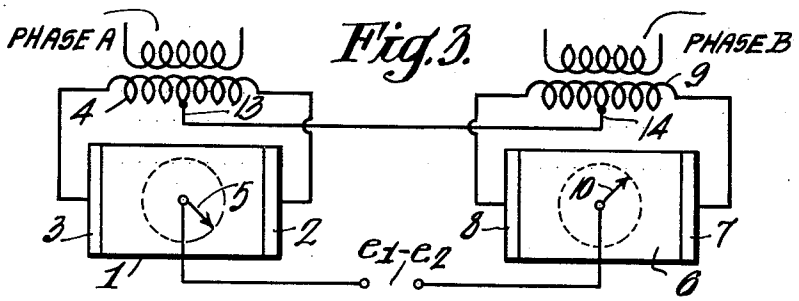


Fig. 4.

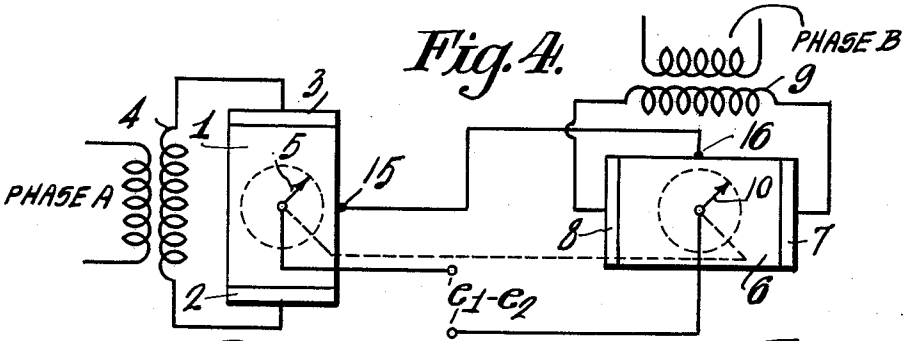
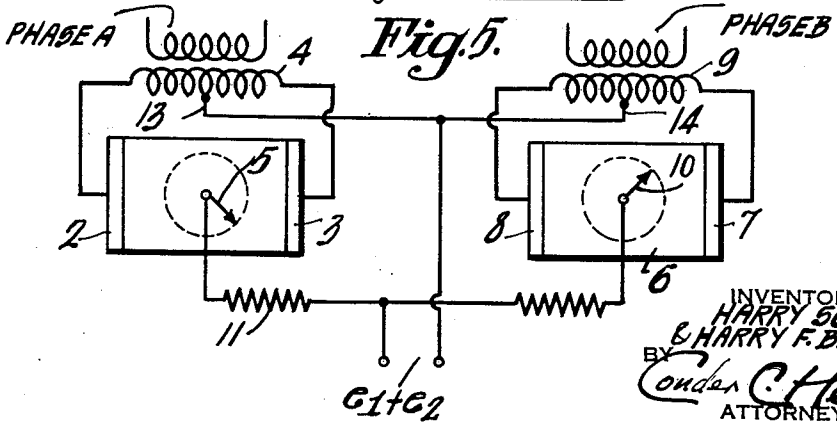


Fig. 5.



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PHASE SHIFTER

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3 Claims. (Cl. 321—57)

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Our invention relates to electrical apparatus and more specifically to a novel device which will shift the phase of an alternating voltage.

Elaborate apparatus heretofore proposed for shifting phase has been prohibitive in cost and in many cases could not be used practically. Delicate adjustments and fragility have also limited the scope of use of prior phase shifters. Furthermore, many phase shifters of the prior art have been dependent upon a function of frequency for their operation because they have used inductances and capacities and therefore have presented different characteristics when operated at different frequencies. These frequency limitations have further necessitated unique design principles for special phase shifting effects and have necessitated complex networks for multiphase use. The simpler phase shifting devices of the prior art do not provide a constant output voltage over an entire 360° of phase shift. In many applications of such phase shifters a change of output voltage with phase shift is intolerable.

It is accordingly an object of our invention to provide a simplified method for shifting phase which will produce a constant output voltage over 360° phase shift, the amplitude of which is independent of frequency or phase shift.

Another object of our invention is to make a cheaply constructed and mechanically stable device which will change phase over an entire angle of 360°, and in which the phase change is directly proportional to the angular displacement of a rotatable arm, without the use of a specially wound and expensive potentiometer.

A further object is to provide a simple means for shifting of a multiphase voltage and for selecting the desired phase angle with one control.

A still further object of our invention is to provide for a simplified means of obtaining special or non-linear phase characteristics.

Briefly, realization of these objects is attained in one specific embodiment of our invention by providing a pair of specially designed potentiometers consisting of flat uniform resistance strips of carbon, or other such resistance material, having two alternating voltages of different phase connected respectively across them. A voltage of variable phase is taken from two ganged rotatable arms which make contact at their radial extremities to the strips. This voltage is of constant amplitude and of phase relationship proportional to the angular displacement of the arms. Multi-phase output voltage may be realized by adding additional contact arms, and

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special phase characteristics may be obtained by changing resistor or slider arm characteristics.

Features of our invention which we consider novel are set forth with particularity in the appended claims. The invention itself, however, both as to its organization and its methods of operation, together with additional objects and advantages, will best be understood from the following description of a specific embodiment, when read in connection with the accompanying drawing, in which:

Figures 1 and 2 show diagrammatically a preferred embodiment of two elements which make up the phase shifter.

Figure 3 shows a phase shifter assembled according to the invention;

Figure 4 is a modification of Figure 3, and

Figure 5 illustrates an alternate means of connecting the phase shifter.

As is shown in Figure 1, the resistance element in the potentiometer consists of a square or rectangular strip, 1, to which voltage of phase A is impressed at the end terminals, 2 and 3. The impressed voltage is taken from an input source, 4, which has a tap, 13, at the approximate center. A slider arm, 5, makes contact with the resistance strip at its radial extremity and is moved in a circular path with its center at or near the center of the strip and with angular displacement, from the line $x—x'$, which may be called the angle θ. Output voltage, e_1, is taken between the slider arm and the tap, 13, on the input source.

The resistance element, 6, shown in Figure 2 is identical with that shown in Figure 1 with voltage of phase B impressed at its end terminals, 7 and 8, coming from a voltage source, 9. Displacement of its slider, 10, is now the angle $(\theta+\alpha)$ and a voltage, e_2, is developed between the slider arm and the tap, 14, on the voltage source.

The two elements are combined in Figure 3 by connections between the taps on the respective voltage sources. Output voltage, $e_1—e_2$, of variable phase is taken in push-pull from between the slider arms, 5 and 10.

In Figure 4 one of the resistance strips, 6, is orientated at an angle α (which is in this case 90°) to the other strip, 1, in order to allow the functional position of the slider arms, 5 and 10, to be parallel for simplified construction. Electrical connections are made directly between points, 15 and 16, on the resistance strips corresponding to taps in the voltage input. Contact arms on the two strips are ganged.

Figure 5 provides a circuit for push-push connection of the voltages e_1 and e_2 to give an out-

put voltage e_1+e_2. This is accomplished by taking the first side of the voltage from a common transformer tap connection and the second side from a common slider arm connection. Two resistors, 11 and 12, are inserted between the respective slider arms and the second common output voltage connection.

Operation of the phase shifter is explained in the following discussion. The voltage e_1 in Figure 1 is effectively the voltage drop between the center line, $x-x'$, of the potentiometer and the point of slider arm contact and may be expressed as $e_1=E \sin\theta \sin wt$ where θ is the angle through which the slider arm has been moved and ω is the angular velocity of the supply voltage.

The voltage e_2 in Figure 2 is similarly expressed as $e_2=E \sin\psi \sin(wt-\alpha)$ where α is the time angle between the two phases of the voltage source and $\theta=\theta+\omega$.

Letting $\alpha=90°$, which is convenient for both electrical phasing and mechanical arrangement, the voltages become:

$$e_1=E \sin\theta \sin wt=\tfrac{1}{2} E \cos(wt-\theta)-\tfrac{1}{2} E \cos(wt+\theta)$$

$$e_2=E \sin(\theta+90°) \sin(wt-90°)=-E \cos\theta \cos wt$$

and

$$=-\tfrac{1}{2} E \cos(wt-\theta)-\tfrac{1}{2} E \cos(wt+\theta)$$

When the midpoints, or other points corresponding to the center of the slider arms, of the two phases are connected together as in Figure 3 the output voltage taken between the sliders will be:

$$e_1-e_2=E \cos(wt-\theta)$$

It is seen that this voltage is of constant amplitude, E, and of phase proportional to the angle θ.

By assembling the two potentiometer elements at the angle α, in this case 90°, as shown in Figure 4, the sliders may be placed in the same direction on the shaft, for convenient mechanical construction.

The two potentiometers are connected with their outputs in push-push instead of push-pull in Figure 5 in which case the resistors, 11 and 12, are connected between the slider arms and the common output connection to prevent short circuit of the output voltage. In this circuit the output voltage is the sum of the component voltages e_1 and e_2 being:

$$e_1+e_2=-E \cos(wt+\theta)$$

which voltage is also of constant amplitude E and of variable phase proportioned to the angle θ.

If for any reason the input voltage phases are not 90° apart in time, $(\alpha+90°)$, the result is still a constant voltage of variable phase proportional to the angle θ. In this case

$$e_1=E \sin\theta \sin wt$$
$$=\tfrac{1}{2} E \cos(wt-\theta)-\tfrac{1}{2} E \cos(wt+\theta)$$

and

$$e_2=E \sin(\theta+\alpha) \sin(wt-\alpha)=\tfrac{1}{2} E \cos(wt-\theta-2\alpha)-\tfrac{1}{2} E \cos(wt+\theta)$$

With a push-pull connection as in Figure 4 the voltage difference is

$$e_1-e_2=\tfrac{1}{2} E \cos(wt-\theta)-\tfrac{1}{2} E \cos(wt-\theta-2\alpha)=-E \sin\alpha \sin(wt-\theta-\alpha)$$

When the connection is made in parallel, however, as in Figure 5, the angle ψ should equal $180°+\theta-\alpha$

and then

$$e_1=E \sin\theta \sin wt=\tfrac{1}{2} E \cos(wt-\theta)-\tfrac{1}{2} E \cos(wt+\theta)$$

$$e_2=E \sin(180+\theta-\alpha) \sin(wt-\alpha)$$
$$=\tfrac{1}{2} E \cos(wt-\theta)+\tfrac{1}{2} E \cos(wt+\theta-2\alpha)$$

The sum is now:

$$e_1+e_2=-\tfrac{1}{2} E \cos(wt+\theta)+\tfrac{1}{2} E \cos(wt+\theta-2\alpha)$$
$$=-E \sin\alpha \sin(wt+\theta-\alpha)$$

It is to be noted that for the push-pull connection $\psi=(\theta-\alpha)$ and for the parallel connection $\psi=180+(\theta-\alpha)$. When changing from series to parallel connection the correct angular adjustment is obtained by interchanging the wires connected to one potentiometer.

Theoretically, the resistance strips should be uniform and continuous, however, for ease of construction it is reasonable to pierce the strip so that the potentiometer shaft can be passed through. The error introduced by this hole is small if its radius is small compared to the radius of the circular track which the slider arm follows.

Additional phases can be obtained from the shifter merely by placing additional arms on the potentiometers, and their phase relationship will be determined by the angular displacement with respect to the initial arms.

Special phase shifting characteristics may be obtained by making non-circular contact arms, special resistance elements, variable strip shapes, or variable voltage feed points.

Because the working elements of our phase shifter are resistance elements, their voltage amplitudes are constant at all frequencies and hence there are no critical adjustments or tolerances in this device, construction is cheap and simple, and the strips may be made to withstand considerable vibration or jolting.

Having thus fully described the nature, construction and operation of our invention, we wish to secure by Letters Patent, and claim:

1. Phase shifting apparatus comprising, in combination; a first block of resistance material having a flat uniform face, a first rotatable contact arm having one end attached substantially in the center of said flat face, the other end of said contact arm being of such a length and so shaped as to contact said face throughout a 360° rotation of said arm, a second block of resistance material having a flat uniform face, a second rotatable contact arm attached to the second block similarly to said first contact arm, a first alternating voltage connected across opposite ends of said first block, a second alternating voltage connected across opposite ends of said second block, said alternating voltages being of different time relationships, an electrical connection between said sources of alternating voltage and a pair of output terminals connected between the contact arms.

2. Phase shifting apparatus comprising, in combination; a first block of resistance material having a flat uniform face, a first rotatable contact arm having one end attached substantially in the center of said flat face, the other end of said contact arm being of such a length and so shaped as to contact said face throughout a 360° rotation of said arm, a second block of resistance material having a flat uniform face, a second rotatable contact arm attached to the second block similarly to said first contact arm, a first transformer having primary and secondary

windings, a first alternating voltage connected across the primary of said first transformer, a second transformer having primary and secondary windings, a second alternating voltage connected across the primary of said second transformer, said voltages being of different time relationships, an electrical connection between the center tap of the secondary winding of said first transformer and the center tap of the secondary winding of said second transformer, and a pair of output terminals connected between the contact arms.

3. Phase shifting apparatus comprising in combination; a first block of resistance material having a flat uniform face, a first rotatable contact arm having one end attached substantially in the center of said flat face, the other end of said contact arm being of such a length and so shaped as to contact said face throughout a 360° rotation of said arm, a second block of resistance material having a flat uniform face, a second rotatable contact arm attached to the second block similarly to said first contact arm, a first alternating voltage connected across opposite sides of said first block, a second alternating voltage connected across opposite sides of said second block, said alternating voltages being of different time relationships, an electrical connection from the approximate center of a third side of said first block to the approximate center of a third side of said second block, and a pair of output terminals connected between the contact arms.

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